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Measuring Atmospheric Dispersion With WLRS In Multiple Wavelength Mode

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Abstract

The WLRS (Wettzell Laser Ranging System) allows the simultaneous tracking of satellites on two different wavelengths. These are the fundamental frequency of Nd:YAG at 1.064 μm and the second harmonic at 532 nm. Range measurements to the satellite LAGEOS were carried out with different experimental set- ups, after developing a detector unit based on a silicon avalanche photodiode in Geiger mode, which is sufficiently sensitive in the infrared domain. An approach towards a quantitative interpretation of the data is suggested and discussed briefly.

1 The effect of atmospheric dispersion on satellite ranges

The varying index of refraction of the atmosphere can be considered one of the most important contributions to the error sources for satellite ranges. Following a model of Marini and Murray [1], the additional time for the laser pulse passing through the atmosphere under an elevation angle of 90 degrees is as much as 8 ns. This model assumes rotational symmetric atmospheric layers with respect to the geocenter and has been established with the help of ballon experiments. Inputs to to this model are atmospheric pressure, temperature and humidity, which are measured around the ranging station. In general it can be said that the calculated corrections are very precise, so that the requirements for an experimental improvement are extremly high [2]. However, orbit fitting procedures on the basis of complex programs often show a small systematic error, depending on the pointing elevation of the ranging station. Therefore a better determination of the atmospheric influence is desirable.

2 The experimental set- up

2.1 The 'two-' detector experiment

When the WLRS telescope was designed [3], care had been taken to optimise the signal path for the fundamental (1.064 μm) and second harmonic (532 nm) wavelength of the Nd:YAG

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laser. The remaining optical components of the ranging equipment were replaced to allow transmission and reception of these 2 frequencies. In the beginning it was not known if the second harmonic generating crystal (KD^*P) would laterally displace the pulses of the 2 frequencies so far, that there would not be a sufficient overlap of the two signals at the location of the satellite. During the experiments a weak dependance of the return rate of each detector with respect to the pointing was noticed. However, the overlap was found to be acceptable. The WLRS- system uses the same telescope for transmitting and receiving, therefore the photodetector was placed behind the transmit/receive- switch inside the thermocontrolled laboratory. This gives the advantage of high signal stability and an easily accessible working enviroment. Figure 1 outlines the experimental set- up. The receive signal is split into its two different frequency components at a dichroic mirror. The signal with a wavelength of 532 nm is reflected towards a microchannel plate (MCP), while the infrared part of the satellite echo is focused onto the active area of an avalanche photodiode (APD: SP114) placed in Geiger mode. In its present state, the WLRS is capable of recording one stop event per outgoing laser pulse only. This causes the detection of either an event from the MCP or the APD. To achieve a high number of echos from both channels, a constant delay- line of 44.9 ns was added to the MCP output, before recombining both signal lines at an impedance matched T - junction and feeding them to the eventtimer. There are two stops for each measured roundtrip possible, only one of them will be recorded, as the electronics gets disactivated after processing one event. The delayline places the less favourable signal channel to be detected first. When the measured return residuals are plotted versus time one can see two signal tracks (fig. 2) separated in range by the delay of the additional cable. This can be noticed during tracking and indicates, if there are enough recordings for both laser frequencies. The contribution to each wavelength has to be separated during the analysis, as all the range information goes to one datafile.

2.2 The 'one-' detector experiment

A slowly varying instability (i.e. drift) in the detector characteristics would be indicated during the ranging run, as a shot by shot calibration to a fixed target is carried out. To exclude such effects generally, the experiment was altered to use just one detector. The dichroic mirror (ref. fig. 1) was removed and the APD recorded both frequencies. The sensitivity of the diode is higher on 532 nm than on 1.064 μm but, because of the dispersion of the atmosphere, the infrared signal reaches the detector first. Therefore, a sufficient amount of data for both signal frequencies can be obtained. For the present this kind of experiment is restricted to the night hours, as there are no suitable spectral filters for this application. During tracking, the operator notices the formation of one track only, as both satellite tracks are separated by their differential atmospheric dispersion delay only, which contributes as much as 0.6 to 1.8 ns. In figure 3 there is a residual plot for such a measurement. In the analysis the two tracks also have to be seperated. To calibrate this measurement a circuit has been developed, which detects the starting oscillation in the laser after the fire command and forms a trigger signal to gate the APD into the Geiger mode before the calibration return hits the diode. This process is extremly time critical. Measurements to the local ground target demonstrate the proper operation of this set- up.

3 Analysing the satellite data

In this approach the question of wether the simultaneous use of different laser frequencies would result in the same satellite range information and, under the condition that a large amount of ranges have been measured, whether the measurements would allow for a correction of the employed atmospheric model were of interest. Therefore the analysis is limited to the differences in the range residuals of the two spectral components. In the following, the measurements obtained at a wavelength of 532 nm are taken as a reference to correct for other satellite ranging side effects; a non linear least squares fitting procedure is employed to fit a polynomial up to the order of 12 to the reference data. In the second step, the range residuals of the measurement in the infrared spectral domain are analysed. It was assumed that this data can be represented by the same polynomial when the additional contribution by the atmospheric dispersion and, if applicable, the extra cable delay is taken into account. Under the condition that the model of Marini and Murray gives a good representation of the atmospheric influence, so that there can be a minor modification to it only, it is:

$$r(t)_{\lambda=1.064\mu m} = r(t)_{\lambda=532nm} - \alpha\mathcal{M}(\omega) - \beta,$$

where $\mathcal{M}$ represents the contribution of the difference of the atmospheric dispersion of the two used laser frequencies depending on the elevation angle ω. α is a dimensionsless scaling factor around the value of 1 and β yields the constant value of the introduced extra delay. The measured range depending on the epoch is given by r. A curve fitting result of $\alpha = 1$ gives the exact representation of the Marini- Murray model. It is a known fact that a possible range correction for this pair of frequencies contributes with a value of only a few ps to the difference between the two used laser frequencies at a given pointing elevation (i.e. a fixed pathlength through the dispersive medium). This can not be taken from the range residual distribution. However, the characteristic elevation dependence of the difference of the ranges of the two laser frequencies places a constraint on the model, such that it might allow an interpretation of the ranging results, especially when a wide range of elevation angles has been spanned by the measurements. At low elevation angles, the separation of the two frequency components is largest, so it is desirable to range down to very low elevation angles. The model has been tested by creating a data set, introducing $\alpha = 1.05$ to an arbitrarily chosen data set of ranges artificially. After running through the evaluation procedure $\alpha = 1.05002$ was obtained as a result. This shows, that a small additionally introduced effect could be well extracted by this procedure. However, this can not be taken as sufficient proof for the applicability of the suggested model modification.

4 The experimental results

Up to now there are two series of measurements, one for each experimental set- up. In figures 4 and 5 the obtained range residuals are plotted versus the angle of elevation. In the lower part of each diagram the fitted data of the reference wavelength ($\lambda = 532\ nm$) is displayed, while the upper half shows the satellite returns taken at the other laser frequency. In all cases a satisfying residual distribution around the fitted curve was obtained. As a side effect, figure 5 shows a higher sensitivity of the photodiode in the infrared spectral range. This was unexpected because the system is at least one order of magnitude more sensitive around 532 nm. The results are summarized in table 1:

Date:	Type	α	$\beta[ns]$
4. Oct. 91	MCP/APD	0.92	44.89
8. March 92	APD	1.02	-0.027

Table 1: The results of the parameter fitting procedure of the 2 LAGEOS passages

In both cases a good representation of the expected contribution of the second laserpulse with a different wavelength was obtained. The passage of LAGEOS, measured in Oct. 1991, shows a small offset from the Marini- Murray formula, but , it is beyond the point of interpretation within the frame of this work. More experience with this measurement technique and much more data are necessary to judge the applicability of this approach. A higher resolution in the measurement of the satellite ranges is also desirable. Therefore, a modification of this experiment using a streak camera is in preparation. The goal is a higher precision in measuring the time difference in the roundtrip between the two spectral components simultaneously. Furthermore, the measurements will be extended to lower elevation angles and the search for APD's with less jitter and noise will also be continued.

Summarizing the present state of the simultaneous ranging on two different laser pulse frequencies, one can say that the obtained ranges under normal atmospheric conditions do not depend on the wavelength of the employed laser.

References

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[3] Schlueter, W.; Hauck, H.; Dassing, R.; Schreiber, U.; Mueller, J.; Egger, D.; *Wettzell Laser Ranging System (WLRS) — First Tracking Results to Satellites and to the Moon, paper presented at the Crustal Dynamics Project Meeting, held in Pasadena, spring 1991.*

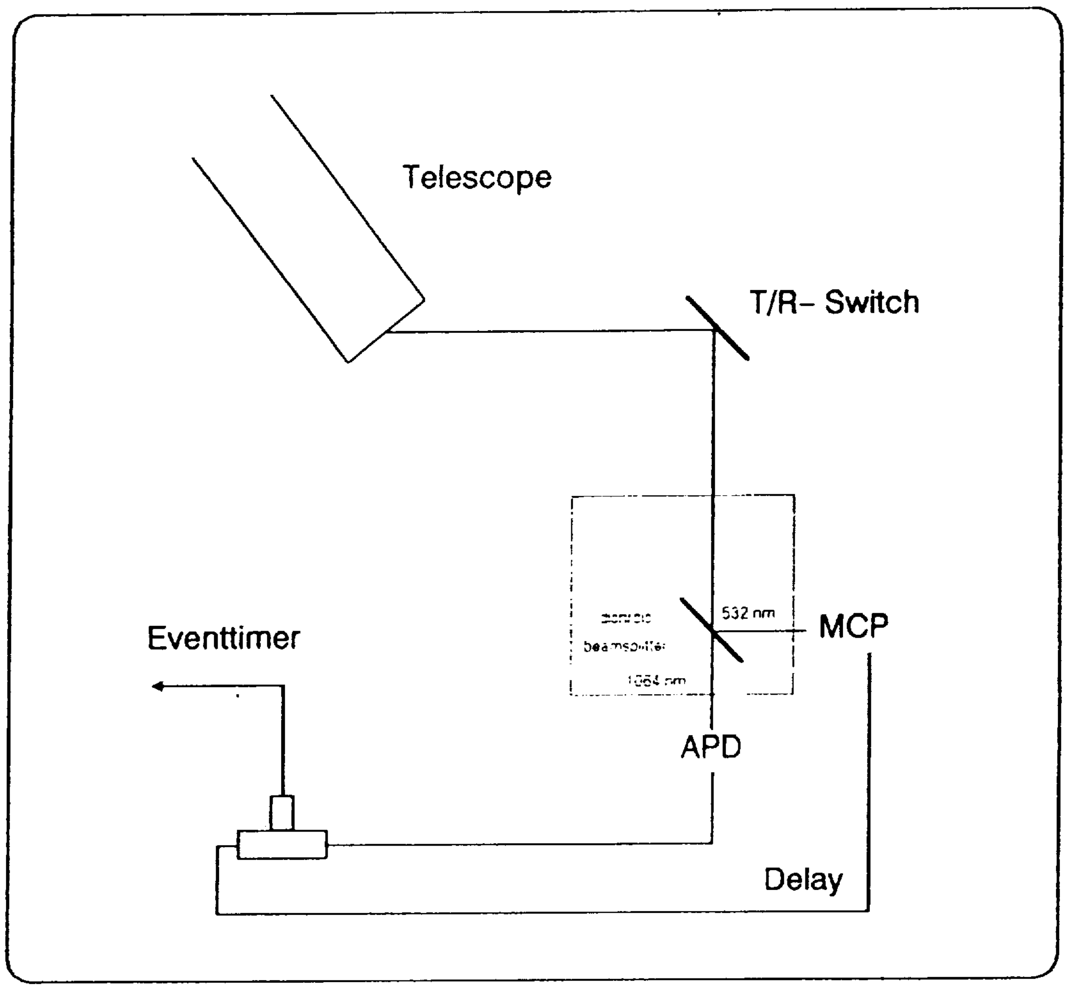

Figure 1: Block diagram for the two detector set- up

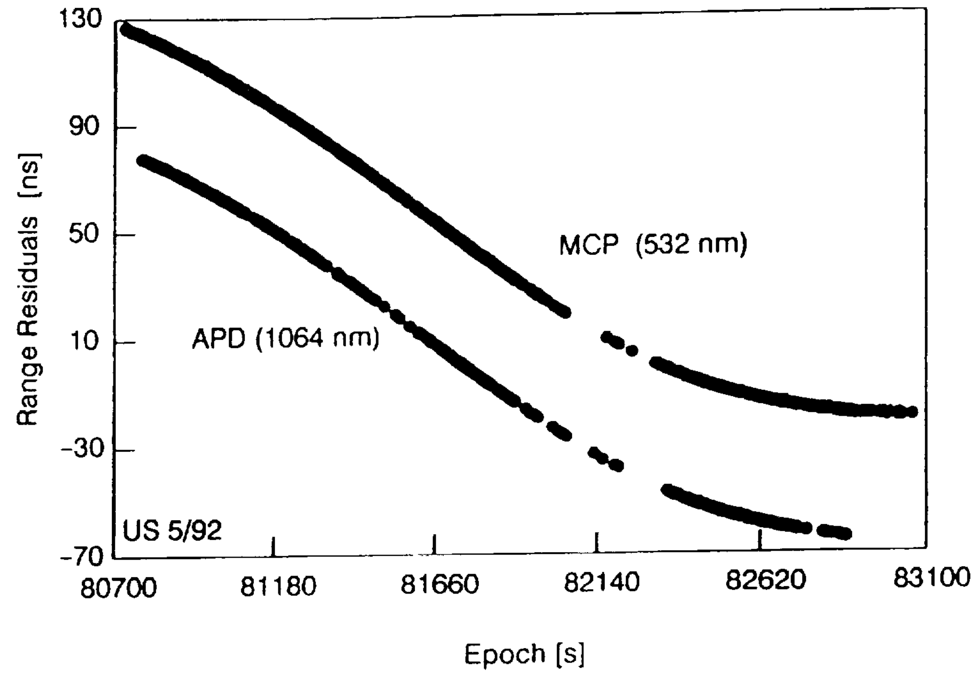

Figure 2: Residual plot of the measured LAGEOS pass from Oct. 4th 1991 after the screening process. The lower track was recorded using the Avalanche photodiode SP114, while the upper track was obtained using a microchannel plate ITT: F 4129 f

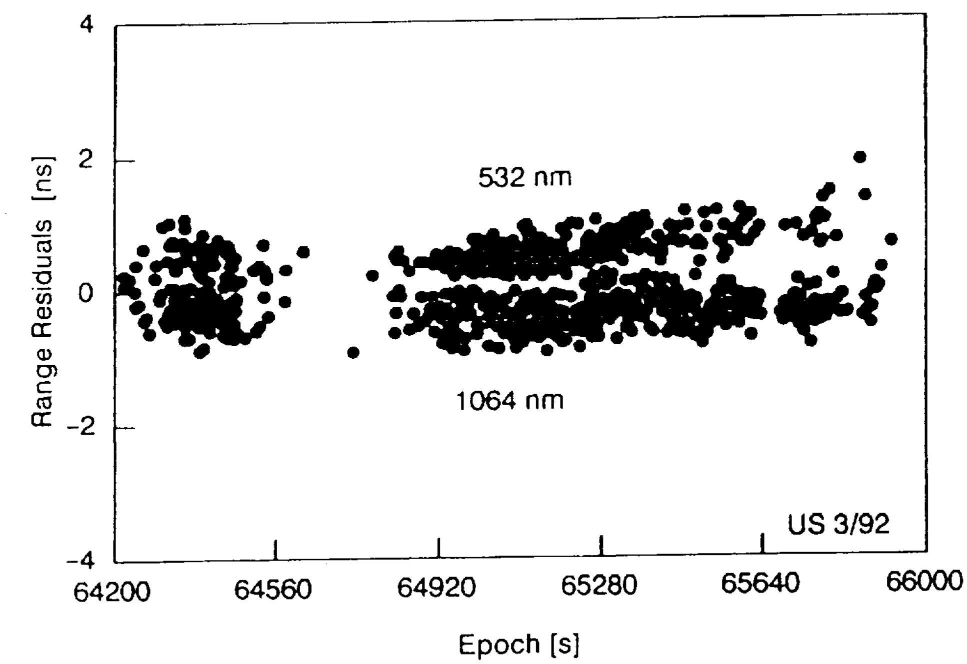

Figure 3: Residual plot of the measured LAGEOS pass from March 8th 1992 after the screening process. Both frequency components were recorded, using the Avalanche photodiode SP114

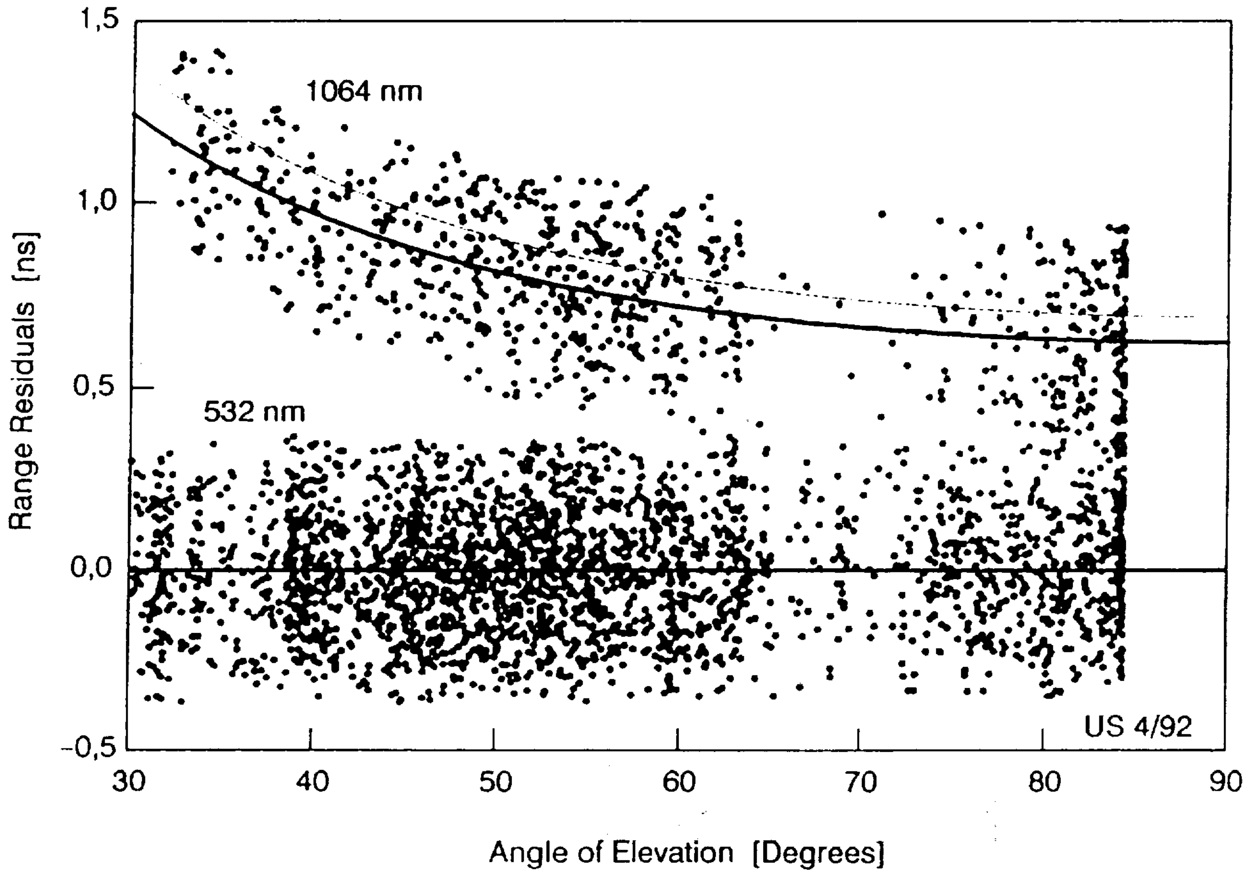

Figure 4: The range residuals of the two different frequency components plotted versus the angle of elevation (satellite: LAGEOS Oct. 4th 1991)

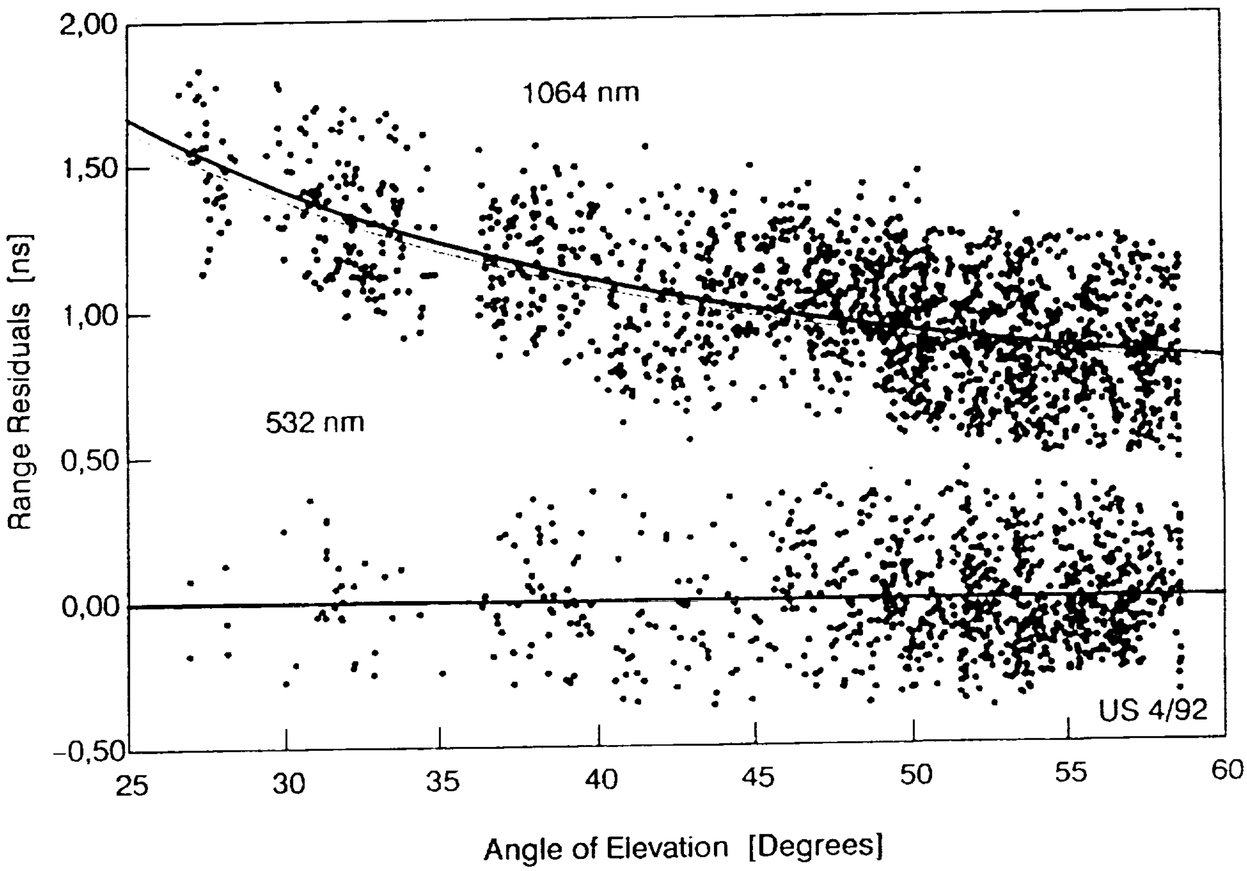

Figure 5: The range residuals of the two different frequency components plotted versus the angle of elevation (satellite: LAGEOS Mar. 8th 1992)